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BRITISH COLUMBIA

Roberts Creek Study Forest: the effects of shelterwood harvesting and blowdown on sediment production in a small zero-order creek

by Robert O. Hudson and Brian D'Anjou

ABSTRACT

A pilot study was conducted to monitor the effect of retaining dispersed dominant Douglas-fir and redcedar within a harvested block on suspended sediment in a small zero-order creek.

Following harvesting, blowdown of susceptible leave trees occurred during the first fall wind storm of the post-treatment season. Three trees that blew down were rooted in the stream channel. Two large pulses of suspended sediment occurred in conjunction with the storm, a result of channel disturbance associated with the in-stream blowdown. Peak sediment concentrations during these events represented a ten-fold increase over pre-treatment levels. Sediment concentrations during subsequent storm events later in the post-harvesting season returned to baseline conditions.

These results suggest that in partial logging operations, trees adjacent to zero-order ephemeral streams should be marked for removal to minimize water quality problems.

INTRODUCTION

The effects of timber harvesting on non-timber resources are of increasing concern to forest land managers in British Columbia. These effects are perhaps of greatest concern in urban fringe areas. One such area is the Sunshine Coast in Southwestern BC, where one of the primary concerns of local residents is sediment production in domestic water supply creeks.

The effects of timber harvesting on sediment production have been extensively studied in the Pacific Northwest. The main causes of increased sediment production due to forest harvesting are surface erosion from roads (e.g., Reid & Dunne, 1984, Duncan et al., 1987, Megahan & Ketcheson, 1996), and burned areas (Brown & Krygier, 1971; Frederiksen et al., 1975; Megahan et al., 1995). Road-related slope failures and streamside logging also contribute large volumes of sediment to streams (Beschta, 1978).

However, there are few studies that look specifically at the effects on sediment production of partial logging systems in streamside treatments. Adams & Stack (1989) noted no change in sediment concentrations under shelterwood and patch cutting systems compared with a control, while a clear-cut unit experienced an eight-fold increase in sediment concentrations. However, specifics of the sediment concentration measurements are not known. Brownlee et al. (1988) found that in a creek in the interior of BC, suspended sediment loading increased four to 12 times over levels in an adjacent control stream. The increase was mainly due to mainline road development. Other sources of sediment included erosion from skid trails, road crossings, and damage to tributary stream banks, but these sources did not persist beyond the first season after harvesting.

The Roberts Creek Study Forest (RCSF) is located on the southwestern flank of Mount Elphinstone on the Sunshine Coast, approximately 40 kilometres northwest of Vancouver, BC (Figure 1). The RCSF is a collection of

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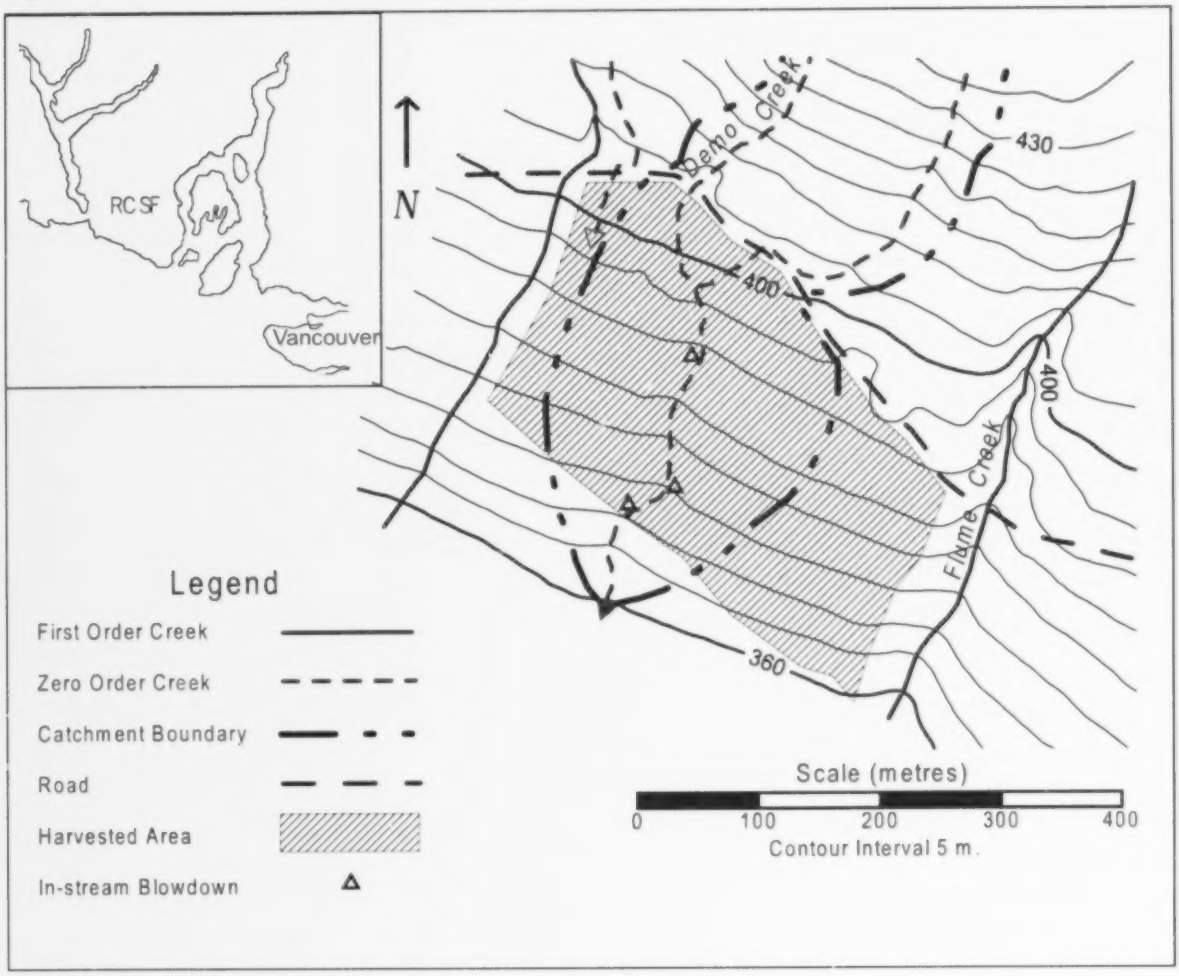
Figure 1: The "Demo Block" study area: Flume Creek, Roberts Creek Study Forest.



adaptive management case studies demonstrating a range of cutting patterns in blocks designed to assist the development of future silviculture prescriptions in the lower elevation, naturally regenerated Douglas-fir dominated ecosystem of the southern coast of the mainland. Within harvested blocks, various aspects of the ecosystem are monitored including stand regeneration, forest stand structure, understory vegetation, mycology, soil invertebrates, wildlife, and hydrology.

Forest hydrology research has been ongoing in the RCSF since 1992. Initial work focused on a demonstration block pilot study, which was undertaken on a 7.7 hectare block, originally planned for clear-cutting, to refine skills related to completing a partial cutting prescription prior to initiating harvesting in the main research project. The "Demo Block" pilot study provided preliminary information on the effect of retaining dominant Douglas-fir and redcedar trees dispersed throughout a harvested block ("uniform shelterwood") on residual stand windfirmness, and its subsequent effect on sediment production.

THE PROBLEM OF BLOWDOWN NEAR CREEKS

The Mount Elphinstone slope is relatively uniform and is dissected by first-order creeks that drain narrow elongated catchments. The interfluves between these first-order creeks are further dissected by zero-order creeks that are capable of carrying substantial peak flows. A zero-order creek (generally classed as S6 under the Forest Practices Code of BC) is difficult to identify through the forest cover in air photos, and therefore generally does not appear on maps. It is ephemeral, does not occupy a clearly defined gully, and where trees are adjacent to the creek, the roots often extend under the channel bed. The high density of zero-order creeks on the Mount Elphinstone slope occurs because of the planar topography and thin soils, despite relatively dry conditions for coastal BC. Areas in which the terrain is more gullied might experience a lower zero-order drainage density.

First-order creeks (also generally S6 creeks, if fish are not present) are perennial and are clearly visible in air photos because they normally occupy gullies. Thus, first-order creeks tend to be used as initial falling boundaries when planning cut blocks. Initial attempts to buffer these first-order creeks in the Mt. Elphinstone area failed because the leave strips were too narrow. Those leave strips blew down, resulting in the sedimentation of the stream. This has led to widening of prescribed leave strips in order to provide a windfirm buffer. Similar experience with leave strips has been documented in Vermont and has led to recommending a buffer strip width of 1.5 times the tree height (Lynch & Corbett, 1990).

There are still questions surrounding treatment of zero-order or S6 creeks that flow through cut blocks. Retention of trees in groups or patches (aggregated) and dispersed is increasing in all areas of coastal BC, and these S6 creeks are directly affected by forest harvesting activities. Due to the number of S6 creeks in areas such as Mount Elphinstone, it is not practical to leave buffer strips of mature timber adjacent to all creeks.[1] Alternatively, reduction of buffer strip width would result in an increased frequency of buffer strip blowdown, leading to widespread sedimentation problems. Since S6 creeks can act as sources of sediment to the creeks into which they flow, this study provided information to help identify the type of riparian management strategies that should be used to protect the integrity of these channels.

STUDY AREA

The gently sloping Demo Block (averaging 11%) is located in the drier maritime subzone of the Coastal Western Hemlock biogeoclimatic zone (CWHdm), between 360 and 405 meters in elevation with a southwest aspect. The local forests, naturally regenerated and previously unmanaged, were initiated by a wildfire in 1860's based on the age of dominant Douglas-fir (*Pseudotsuga menziesii*), which reach 55 meters in height. Western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*) dominate lower tree strata.

Demo Creek, a zero-order S6 stream, flows through the block (Figure 1). Soils are classified as Humo-Ferric Podzol; humus is thin (<5 cm), and there is an impermeable, root-restricting layer between 75 and 80 cm. Across the middle of the block, a bench with hardpan near the surface causes groundwater seepage under wet conditions, resulting in shallow-rooted trees. Similar wet conditions also occur adjacent to Demo Creek. The block is bounded on the east side by East Flume Creek, and on the west by West Flume Creek, both first-order streams.

Demo Creek was not considered temperature sensitive or dependent on large woody debris or streamside trees to maintain channel or bank stability. Thus, because the creek is S6 it did not warrant any specific riparian treatment under the Forest Practices Code of BC Act and its regulations. East and West Flume Creek are also S6 creeks, but were buffered with leave strips. The falling boundaries were flagged about 10 m back from the slope break for a mean buffer width of 20 m from the stream edge to the falling boundary, with edges feathered further into the block to minimize windthrow hazard.

The silviculture system prescribed for the block was a Uniform Two-pass Shelterwood with Reserves. The original goal was to retain dominant Douglas-fir and western red-cedar in a dispersed pattern at a density of 90 stems per hectare (sph) by marking leave trees at a spacing of 10.5 metres. Post-marking stand cruise indicated 90 stems per hectare were retained. Eight yarding corridors were subsequently located, ranging in length from 180 to 230 meters and between 30 and 60 metres apart. Trees were felled into the corridors and a Cypress 6280B swing yarder, rigged with a running skyline, was used to yard the trees to the roadside. Trees marked for retention and located within yarding corridors were not replaced. This effectively reduced residual stand density to 57 stems per hectare, consisting primarily of Douglas-fir assessed immediately after harvesting.

METHODS

A stream gauging site was established on Demo Creek prior to harvesting, at a point 50 m below the lower boundary of the block. The catchment area of the creek at that point is about 15 ha. The instrumentation included a V-notch weir to control the flow, a stage recorder, and an automatic sampler. Stage was measured with a Unidata capacitive water depth probe, and average values were recorded on a Unidata Starlogger 6004-21 data logger at a log interval of 15 minutes. Stage was converted to stream discharge after the fact using a mathematical formula that relates head over the weir crest to discharge, and corrected for subsurface leakage (the leakage factor was assessed by periodic manual discharge measurements collected with a current meter). The data logger was programmed to send a signal to the ISCO 3700 automatic sampler when a predetermined change in stage occurred. The ISCO then collected a sample, and recorded the date and time when the sample was collected.

Water samples were also collected manually on creeks bordering the block on the eastern and western block boundaries during the monitoring period, for suspended sediment analysis. The purpose of the manual sampling was to act as a pseudo-control for the Demo Creek sediment levels. The manual and ISCO samples were sent to the Water Survey of Canada lab in New Westminster for analysis of suspended sediment concentration (SSC). A continuous record of SSC

[1] In the Phase 2 area of the Roberts Creek Study Forest (Flume Creek Experimental Watershed), the average distance between zero order creeks is about 170 metres. If the mean buffer width of 20 metres from the stream to the falling boundary was applied to all zero order creeks, it would reduce the harvestable forest land base by 23%, and likely isolate a substantial portion of the remaining timber.

An analysis was conducted to determine the effects of leaving mature-timber buffers on all creeks, on timber supply in the Vancouver Forest Region. Results showed that if all Riparian Management Zones on S4, S5 and S6 creeks were treated as reserves, the estimated impacts are in the range of 20% to 25% of the timber harvesting land base (Myles Mana, Vancouver Forest Region, personal communication).

was estimated for each storm that was sampled, using relationships between observed SSC and streamflow. Separate relationships were used for rising and falling SSC. This estimated record allowed the sediment yield during the storm to be calculated.

Rainfall was monitored at a nearby site using a tipping bucket rain gauge with a 1-mm resolution. This setup records the occurrence of rainfall-runoff events and provides data points of suspended sediment concentration on the rising and falling limbs of runoff hydrographs. Using this instrumentation, the creek was monitored for two seasons – one season before and one after the harvesting treatment. Monitoring began in late fall 1992, and was discontinued in May 1994. Harvesting was carried out in early fall 1993.

RESULTS

In the 1992-93 pre-treatment season, peak flows reached about 27 litres/second. Maximum total daily rainfall for the season was 35 mm, occurring on 23 March. The largest peak flows occurred on 24-28 January due to rain-on-snow (Figure 2). Some of the flows during the January event had to be estimated from manual measurements (collected by current metering) because the weir was overtopped. Following that event, the weir was built up using sandbags to channel all flows into the structure. The event of 21-23 February was due to rainfall; thus, although the rainfall volume and intensity was greater than for the January event, the peak flow reached only 18.8 litres/second (Figure 3). Suspended sediment concentrations among samples collected during the pre-treatment season were all between 0 and 4 mg/l at Demo Creek, and also on adjacent creeks (Figures 2, 3).

Table 1: Stand structure before logging, after harvest and after blowdown.

Pre-logging	Total	Fir	Cedar	Hemlock
Volume (m^3/ha)	1165	929	45	191
Average height (m)	44.5	48.0	34.0	37.0
Stems/ha	670.7	394.4	118	158.3
Average DBH (cm)	40.2	46.5	23.2	32.3
After harvest				
Volume (m^3/ha)	249	237	12	N/A
Stems/ha	57.4	51.9	5.5	N/A
Average DBH (cm)	62.5	64.4	40.5	N/A
After blowdown				
Stems/ha	48.8	46.0	2.9	N/A
Average DBH (cm)	65.0	66.1	39.7	N/A

Post-harvest surveys revealed that the harvesting operation caused low disturbance of soil surface. Mineral soil exposure occurred over 6% of total surface area and potentially degraded soil conditions on less than 1% of the block, primarily in corridor centers where logs hit the ground due to inadequate suspension (D'Anjou, 1997). Two separate storm events, during 8-12 December 1993, resulted in the blowdown of 66 trees (46 Douglas-fir, 20 western redcedar), reducing the residual stand density to just under 50 stems per hectare (Table 1). Trees tended to fail at the root system, resulting in overturned root wads. Almost half the redcedar blew down, with some trees demonstrating stem breakage. Of the 46 Douglas-fir that blew down, most were concentrated in the seepage band in the middle of the block where trees were

Figure 2: Rainfall, Streamflow (Q) and Suspended Sediment Concentration (SSC) at Demo Creek, January 1993

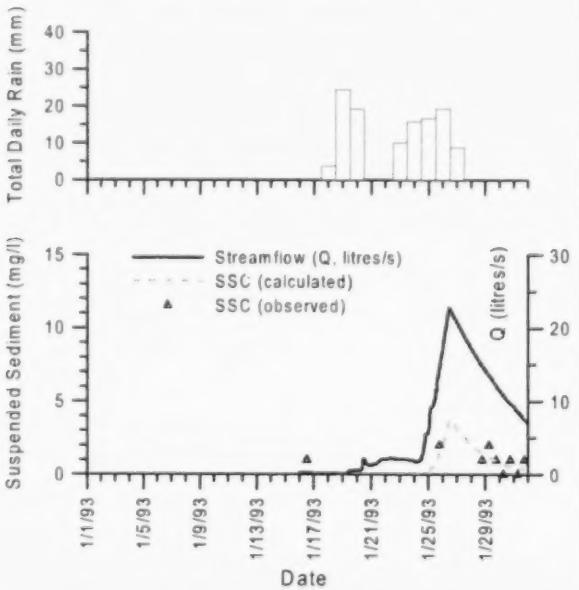
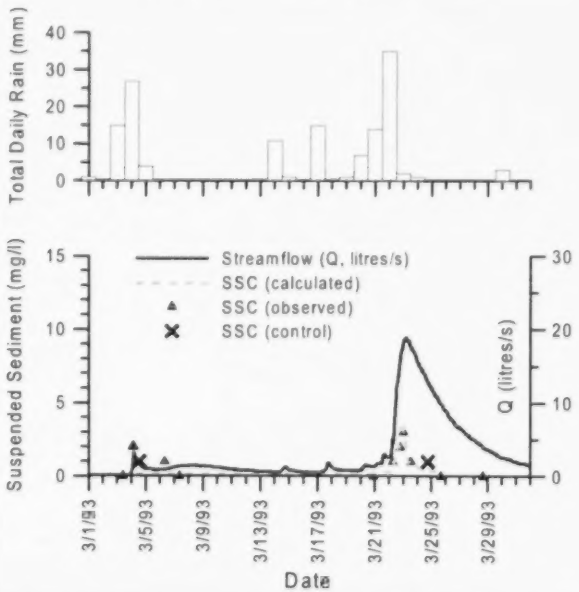


Figure 3: Rainfall, Streamflow (Q) and Suspended Sediment Concentration (SSC) at Demo Creek, March 1993



shallow-rooted. Three of the Douglas-fir trees that blew down within the block were rooted in the creek channel (Figure 1). This blowdown caused loosening of channel sediments and bank disturbance that resulted in creation of erodible sediment sources in the channel.

In contrast to the pre-treatment season, the 1993-94 post-treatment season saw higher peak flows. On 14 December, the weir was overtopped and the range of the water level probe was exceeded by the flow; it is estimated that peak flows reached about 70 litres/second in response to 55 mm of rain that fell the previous day (Figure 4). Three separate runoff peaks occurred from 9-13 December. The blowdown that occurred in the stream resulted in an initial pulse of approximately 53 mg/l of suspended sediment on the rising limb of the runoff hydrograph on 10 December, and a larger pulse of 159 mg/l of suspended sediment early in the morning of 13 December.

This is typical of sediment production during runoff events, in that sediment pulses occurred on the rising limb of the hydrograph, and the sediment concentration was proportional to the peak flow of each event. These pulses were most likely the result of channel and bank scour of the sediment sources created by the three windthrown trees.

Immediately following the December storms with their associated blowdown and resultant sediment production events, suspended sediment concentrations in Demo Creek returned to levels that were comparable to those of the pre-treatment period, and to those at the control sites. The second biggest storm of the season, occurring on 15-17 February 1994, resulted in a peak flow of about 52 litres/second and produced an instantaneous peak in suspended sediment concentration of only 6 mg/l (Figure 5). Thus, blowdown had an immediate but short-lived effect on water quality.

DISCUSSION: THE CONSEQUENCES OF RIPARIAN BLOWDOWN ON DOWNSTREAM RESOURCES

The effects noted above that occurred on Demo Creek seem significant, but the effect of unwanted sediment pulses on downstream resources is more important than the effect of sedimentation on Demo Creek itself. Demo Creek does not support any fish or water users. However, it is a tributary of Flume Creek, which supports a large number of domestic

Figure 4: Rainfall, Streamflow (Q) and Suspended Sediment Concentration (SSC) at Demo Creek, December 1993

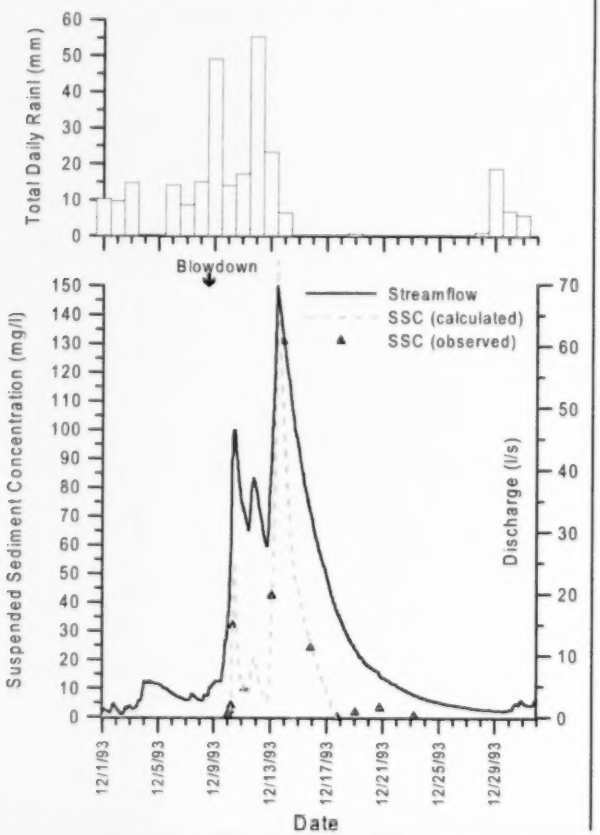


Figure 5: Rainfall, Streamflow (Q) and Suspended Sediment Concentration (SSC) at Demo Creek, February 1994

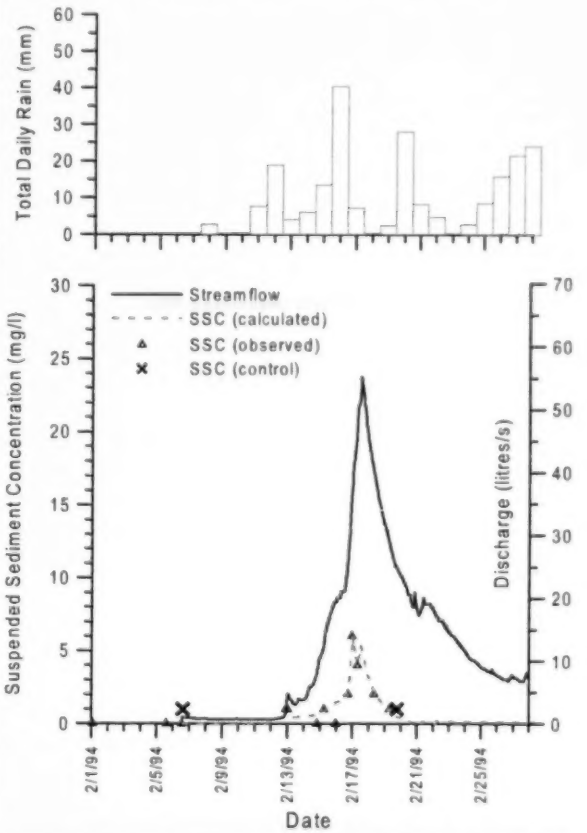


Table 2: Flow and sediment production characteristics of four storms on Demo and Roberts Creeks

			Demo Creek			Roberts Creek		Estimated SS Roberts Creek	
Date	Flow Duration # days	Peak Flow (m^3/s)	Total flow Volume (m^3)	Peak SSC (mg/l)	Total SS Yield (kg)	Peak Mean Daily (m^3/s)	Total Flow Volume (m^3)	Peak SSC (mg/l)	Total SS Yield (kg)
24/01/93	8	0.0228	8788	3.8	15.8	4.60	1967760	3.7	3598.1
20/03/93	12	0.0188	6922	3.5	5.0	8.34	2124662	3.4	2014.9
08/12/93	10	0.0697	30556	158.9	1132.6	15.60	4760640	7.1*	12952.3*
Estimated baseline conditions for 08/12/93 storm:				7.4	42.7			6.6	11862.4
12/02/94	15	0.0514	22386	6.0	34.7	11.80	3305318	5.7	9799.1

* estimated consequence of an isolated riparian blowdown event (similar to the Demo Creek event) in Roberts Creek.

water licenses. Similarly, other zero-order creeks in the Mount Elphinstone area contribute flows (and sediment) to fish bearing creeks such as Roberts Creek, which has been gauged by Water Survey of Canada since 1959.

The effects of isolated sedimentation events (such as the 10-13 December 1993 events) on mainstem creeks can be estimated by comparative analysis of peak flows and storm flow volumes (Table 2). Assuming that sediment production in Demo Creek during the storms of 24 Jan 93, 20 Mar 93, and 12 Feb 94 is representative of background sediment production within Roberts Creek drainage, peak SSC and total sediment yield in Roberts Creek can be estimated from relationships between suspended sediment and streamflow.

Results from sediment production studies elsewhere in the Vancouver Forest Region, such as Russell Creek, (Hudson and Sterling, 1998) suggest that peak SSC may be related to peak flow, whereas total storm sediment yield may be related to flow volume. Therefore, relationships were developed to predict the peak SSC and total SS yield that would have resulted from the December 1993 event in Demo Creek had the blowdown not occurred, using data from the storms representing baseline conditions. Similar relationships were developed to predict baseline SSC and SS yield in Roberts Creek for the four storms in question. Excess sediment generated by the December 1993 blowdown event in Demo Creek was calculated by subtracting the estimated background from the observed SSC and SS yield. Then, the effect that the excess sediment would have had on Roberts Creek was estimated by dividing the excess SSC and SS yield by the dilution ratio of Roberts Creek over Demo Creek, and adding the resulting excess to the estimated baseline of Roberts Creek.

These calculations show that a blowdown event similar to that which occurred in Demo Creek would likely have increased peak SSC and total storm sediment yield by about 9% in Roberts Creek, assuming that all the sediment was transported out of the watershed during the same storm. Clearly, the effects of riparian blowdown on one-zero order creek are not substantial, but the cumulative effects of many such instances occurring across the landscape in a given storm could have a serious effect on downstream water users or fish habitat. Those effects could include potential fouling of water intakes, contamination of drinking water, and sedimentation of spawning gravel.

CONCLUSIONS AND RECOMMENDATIONS

Although current field assessment procedures (Form FS 712-2) suggest moderate windthrow hazard due to topographic exposure and soil factors within the study area, forest stand attributes including uniform structure, tall trees (exceeding 30 meters) and height/diameter ratio (exceeding 90) point to high hazard. Three of the Douglas-fir trees that blew down were adjacent to the channel, with roots that extended under the channel bed. In spite of the lack of real control data, it is clear that the main water quality effect on Demo Creek associated with the uniform shelterwood harvesting was an intense but short-lived sediment production event, the result of blowdown in the channel of only three trees. Peak sediment concentrations during this event reached roughly 10 times the expected level for that creek under non-harvest conditions, based on data obtained from the pre-treatment period, from post-blowdown storms on Demo Creek, and from the adjacent "control" creeks. If those trees had been marked for removal rather than retention, the observed sediment pulses shown in Figure 4 would not have occurred.

The riparian management of the first-order creeks has been successful in that there has been no blowdown in the buffer strips. However, because of the high density of zero-order creeks at Mount Elphinstone it is not practical to establish buffer strips around all of them. Furthermore, it is likely that trees adjacent to zero-order creeks will tend to be shallow-rooted because riparian areas generally experience wetter soil conditions than non-riparian areas. Thus, in areas where windthrow hazard is high, trees adjacent to zero-order creeks are likely susceptible to blowdown.

This suggests that for zero-order streams under partial harvesting systems where removal is relatively high, the proper streamside management prescription is to remove trees with a high windthrow potential that are adjacent to the channel. It is generally true that trees with high windthrow potential should be marked for removal while every effort should be made to retain non-merchantable understory vegetation in order to maintain stream channel stability. Removal of windthrow-prone trees will increase the chance of meeting the target overstory retention over the long term, and help to protect the integrity and sediment production characteristics of zero-order creeks within the block.

The results of this pilot study suggest that at Roberts Creek,

first-order and zero-order creeks require different riparian management strategies, even though both are classified as S6.

1. Under the FPC, S6 creeks do not require buffers. However, at the Demo Block it was considered appropriate to buffer first-order S6 creeks with leave strips of mature timber. Although it is considered impractical to buffer the zero- order creeks, the results of this pilot study suggest that they warrant some riparian management to prevent water quality problems from developing that could adversely affect downstream resources. The management strategy should be specific to the partial harvesting system being used.

2. This pilot study has shown that channel damage related to blowdown was the cause of the observed sedimentation problem that occurred after logging. These results suggest that when managing zero-order ephemeral creeks in uniform shelterwood and other partial logging systems, any trees with high windthrow potential that are adjacent to the channel should be removed to prevent potential sedimentation problems. It also follows that steps should be taken to prevent damage to the stream banks from other sources. This may involve falling away from the channel and either yarding away if feasible, or yarding over the creek with full suspension.

3. Other management objectives aside from water quality, such as wildlife habitat, may require the preservation of buffer strips along zero-order creeks. In the Roberts Creek Study Forest, we found that a buffer strip width of 20 metres, with edge feathering and/or canopy pruning, was effective at protecting the riparian areas of S6 creeks from blowdown.

LIMITATIONS

As noted above, the study described here was a pilot study intended primarily to gain experience with methods, and not a controlled experiment. Adjacent creeks that did not receive harvesting treatments were sampled as control sites, but only sporadically. Streamflow was not measured on those creeks during the study period. Furthermore, in most sediment budget studies currently conducted by the BC Forest Service and others, continuous turbidity measurements are collected in conjunction with sampling for suspended sediment analysis (Hudson, 1996), so that continuous sediment fluxes can be reconstructed. This was not done at Demo Creek. Therefore, any results obtained from this study are not conclusive.

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